STATIC AND DYNAMIC BALANCING.

Paper presented to the Institution, London Section, by W. I. Senger and Ed. L. Addleton.

IN preparing this paper, we have purposely omitted any description or comparison of competitive balancing machines and in any discussion that may take place after the paper is read I should appreciate it very much if the trade name of specific balancing machines is not mentioned, for a brief description of the type of machine in the questioner's mind will be sufficient to enable me to give an intelligent reply that should be understood by all present.

As most of the data in the following paper together with the photographs and charts are from the records of Mr. Senger's and my own firm, I must crave your indulgence that the photographs shown are only of one type of static and dynamic balancers, but when I make the statement that these records and photographs are from a firm that is the pioneer of simplified balancing, I am sure that you will grant me this indulgence.

With most engineers, balancing is looked upon as a necessary evil and something that should be wished on to any department other than their own, but once the fundamentals are understood and with the help of modern balancing machines, it is as simple an operation as any others that go through the shops. The question of design is only touched upon in this paper where necessary as at the time at our disposal it was impossible to go into this thoroughly.

Introduction.

As the size and speed of machinery has increased it has become more and more important to find the source of and eliminate the vibrations which are of an objectionable or destructive nature. The importance of correct balancing of rotating parts is particularly evident in high speed machinery since the centrifugal effect of any given amount of unbalance increases as the square of the speed as graphically shown by the force chart (Fig. 1). From this we find that the unbalance caused by a mass of only one ounce at a distance of 10-ins. from the axis of the rotating body will have a centrifugal force of 159.5 lbs. at 3,000 revolutions per minute, which, in other words, delivers a blow of nearly 160 lbs. fifty times per second with objectionable effects which are readily apparent.

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Mechanical Difficulties Eliminated by Proper Balancing.

Although in many lines of manufacture, and in the automotive industry in particular, balancing first attracted the serious attention of engineers as a means of obtaining smoother performance and greater comfort for the operator and his passengers and thus increasing the sales appeal of the product, the accurate balancing of the crankshaft and other principal rotating parts has brought many other benefits besides making the modern car more agreeable to drive than in the days before equipment was available which made such accurate balancing commercially practicable and economical.

The increase in bearing life has been tremendous due, of course, in part to better bearing metals, better lubrication, and better design throughout, but it is also obvious that excessive wear or pounding out of bearings was often due to the unequal distribution of mass in the body carried by the bearing and hence bearings designed to carry only the normal load, due to the weight of these rotating parts, may easily be overloaded and wear excessively when the load, due to the unbalance, is added to the normal bearing load.

Another mechanical difficulty which can be eliminated by balancing is a reduction in the parts broken, due to overloading or to synchronous vibration of the machine members under the periodic action of the unbalanced parts. For example, a shaft may be just strong enough to carry the weight of the rotating body, but due to the unbalance in the body, the shaft may be overloaded and fail.

Again, large amounts of power are lost in machinery in which there are unbalanced parts. Some of this loss is due to an increase in bearing loading with a consequent increase in bearing friction. This increase in bearing friction makes necessary the use of more lubricant in an attempt to reduce this friction. However, the power lost in bearing friction is small compared with the power which may be consumed by absorbing vibration in the foundation of the machine. The energy which can be absorbed thus has been experimentally demonstrated by mounting a small electric motor on a table and providing means by which the speed of the motor could be increased by small increments. Attached to the motor shaft was an eccentric weight to unbalance the motor, and as shown in Fig. 2, at a speed of 310 revolutions per minute, it was possible to increase the power input to the motor from about 12 watts to 25 watts without any increase in the motor speed. At this particular speed considerable vibration of the table legs was apparent and the energy required to produce this vibration came from the power put into the motor which performed no other work but was entirely dissipated in the vibration of the motor base and table. Again at about 750 revolutions per minute a considerable vibration of the table took place and again large increases in the power input caused no increase in motor speed.

The conclusions obtained from this experiment are amply borne

out in practice and many cases are on record in which it has been found that vibration of the foundation has materially reduced the mechanical efficiency of the machine. Proper balancing of the rotating parts of a machine will eliminate most of the power loss. One instance of this kind may be cited in which the power loss due to the unbalance and resulting vibration practically caused the rejection of equipment furnished by a reliable manufacturer. This manufacturer had made an installation of multi-stage centrifugal pumps in a large power plant, which, on test, failed to give the guaranteed efficiency The pump impellers were then removed and taken to an accurate balancing machine after which they were returned to the power plant and again put back into the pump. Nothing was done to any of the units in this installation other than proper balancing of the pump impellers and on their second test the pumps then showed an efficiency above that which had been guaranteed.

In addition to the mechanical difficulties and power losses due to unbalance as already discussed, many machines do not function properly if the rotating parts are not balanced. The rolls used for making sheet steel plates for automobile bodies must be very well balanced or the plate produced will show waves when it becomes a part of the automobile body. A similar condition will be produced in paper made in a machine having unbalanced rolls.

Unbalanced holding fixtures used on machine tools such as lathes or grinding machines frequently make it impossible to do perfect turning, boring or grinding. With the introduction of new types of high speed cutting tools, the speed at which machine tools operate has increased very rapidly, thus increasing the necessity for balanced holding or chucking fixtures.

Although one can seldom improve the quality of a manufactured product without a corresponding increase in its cost, the art of balancing and the modern machines developed for this process have been so perfected that the balanced unit now frequently costs less than the corresponding part before it was balanced, due to the elimination of many costly machining operations by balancing. For example, high speed pulleys were frequently machined all over in an attempt to produce a smooth running part. Now only the essential surfaces of these pulleys need be machined and by balancing a cheaper and much better pulley is produced. Formerly automotive crankshafts were machined all over. Now a balanced crankshaft on which only the crank pin bearings and the main bearings are machined is actually a better, cheaper, and smoother running crankshaft than was formerly produced by finishing all over.

It is generally assumed that balancing is done for the sole purpose of eliminating vibration which may be annoying to the operator of the machine. At one time, such was undoubtedly the reason for balancing the automobile crankshaft. However, balancing of

crankshafts has made it unnecessary to finish the cranks all over and the balanced crank of to-day with less machine work runs more smoothly than the expensive all finished crank of several years ago. Recently this same feature has been proven out on cone pulleys for the Henry and Wright sensitive drilling machines. These pulleys are no longer turned on the inside as balancing is giving a smoother running job with a lower total cost. Thus, balancing can often be made the means of giving a better product at a less cost, then the balancing machine actually becomes a production tool.

Vibration and the mechanical difficulties due to vibration also make it desirable to balance parts of a machine. Some of the mechanical difficulties are :—

(1) Excessive bearing wear due to the overloading of bearings when the load due to unbalance is added to the normal bearing load.
(2) Breakage of parts when the load due to unbalance is added to the normal load.
(3) Excessive power loss in bearing friction when parts are not balanced.
(4) Improper functioning of a machine with unbalanced parts. The Heald Size-matics, Henry & Wright sensitive drilling machines, and Landis grinders require balanced pulleys and spindles to maintain accuracy of workmanship.

Sources of Vibration.

Before discussing more fully the various balancing processes and types of balancing machines, it may be well to point out the various kinds of vibration and the sources from which these may occur in any high speed machine.

Whipping speed.—One of the most common sources of vibration is the tendency of any rotating shaft to vibrate at its whirling speed which is often commonly referred to also as it's " whipping speed " or " critical speed." At such speeds any design of shaft will become dynamically unstable and vibrations of considerable magnitudes are likely to develop. This whirling speed is the speed at which the number of revolutions per second of the shaft is equal to the natural lateral frequency of vibration. As a matter of fact, the amount of whip or deflection of the shaft may be of considerable magnitude at speeds *slightly* above or below the true critical speed while at *considerably* above the critical smooth running conditions again prevail.

Vibration from this source can only be eliminated by proper design and since this critical speed may be easily determined by graphical means for any particular shaft and the design of the shaft may be varied to give the desired results, all machinery designed for operation at high rotating speeds should be designed so that this critical

or whipping speed is at least 20 per cent. above or below the operating speed of the shaft.

Torsional vibration.—Another common source of vibration is the torsional vibration between sections of a shaft. Assuming a shaft rigidly held at one end with a flywheel on the other end of the shaft,

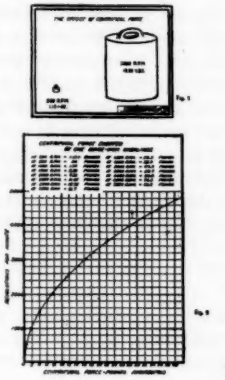


Fig 1

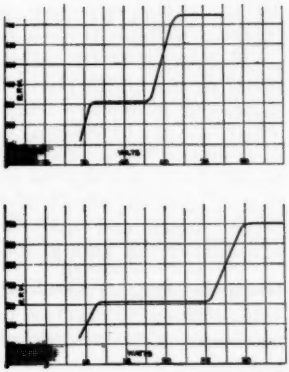


Fig 2

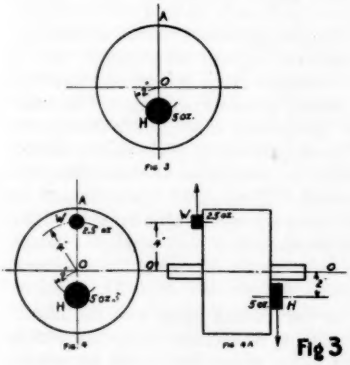


Fig 3

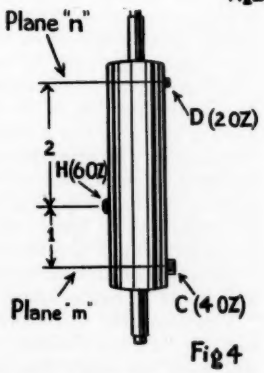


Fig 4

it is apparent that if a torque be applied to and suddenly removed from this flywheel in the plane of the flywheel, the flywheel will execute free torsional vibration and it can be shown that this torsional vibration is periodic. If the shaft with one end fixed were replaced by a shaft with a flywheel on each end, it is apparent that even while the shaft is rotating the flywheels may perform torsional oscillation. In cases of this sort, there is always some intermediate

transverse section in the shaft which is not subject to this torsional oscillation, this section being called the nodal section. The flywheels will move in opposite directions with respect to a point in the nodal section in such a way that the momentum of the system is equal to zero. In the case just presented, it was assumed that the shaft was of constant diameter throughout its length, but if the shaft diameter varies, the problem can be reduced to one in which the shaft has a constant diameter because the angle of twist of a shaft is proportional to the length of the shaft and is inversely proportional to the fourth power of the diameter. Diesel engine crankshafts and automotive crankshafts of considerable length are particularly subject to torsional vibration as are gear systems in machine tools and in drives of different sorts but fortunately the effects of torsional vibration may be quite effectively counteracted by a simple type of torsional vibration dampener at the ends of the shafts and proper design and analysis of the system can largely eliminate vibration of this kind at its source.

Reciprocating or Oscillating Parts.

In addition to vibration from the sources described above, many machines which have reciprocating or oscillating parts are subject to extreme vibration. An outstanding example of vibration of this type can be had in the single cylinder petrol engine. However, it is not to be supposed that the parts which only have a pure reciprocating motion are alone capable of giving this type of vibration. The connecting rod in an automotive engine, although it has a combination of reciprocation and rotation does create a vibration due to the portion of its motion which is reciprocating. The connecting rod also has a swinging or oscillatory motion which sets up vibration. The vibration set up by reciprocating parts is due to the tremendous inertia forces which must be overcome in order that the motion of the body may be reversed. Then after the reversal of the motion these bodies must again gain a considerable speed. This extremely rapid acceleration and deceleration and abrupt change in direction of movement can only be given by a part of the machine and tends to cause vibration.

Vibration due to reciprocating or oscillating parts can be eliminated by the introduction of reciprocating or oscillating bodies which will have the same motion in the same plane but with an effect opposite to that of the disturbing body. It is also possible to eliminate these vibrations by means of unbalanced rotating bodies and by analysis of the direction and magnitude of the forces developed by the reciprocating or oscillating bodies it will be possible to introduce a series of unbalanced rotating bodies of proper magnitude and phase to counteract these forces or at least to counterbalance them sufficiently to eliminate most of their harmful effects.

Unbalanced Rotating Bodies.

The types of vibration just discussed can all be eliminated or greatly reduced by proper design, but there are still other sources from which destructive vibration may develop even in properly designed machinery. The cause of these vibrations is unequal distribution of mass in the rotating parts of the machine. This unequal distribution of mass may be due to the lack of homogeneity in the materials used, to the irregularity in the unmachined portion of the rotating body, or to irregularity in the machining of the body.

In modern properly designed machines unbalance in the rotating parts from these sources gives the principal cause of vibration and sets up the tremendous centrifugal effect already discussed and various types of balancing machines have been developed to measure the effect of this unequal distribution of mass and to point out its position and indicate the amount of weight to be added or removed from the body to secure a uniform distribution of mass about its axis of rotation, so that this body under rotation will not exert any variable disturbing force on its supports. This condition cannot be produced repeatedly by the ordinary manufacturing processes because in addition to the errors of manufacture the distribution of mass will not be uniform due to the non-homogeneity of the material.

Static and Dynamic Unbalance.

Balancing machines are ordinarily arranged to measure unbalance in the parts in ounce inch units, which represents the centrifugal force produced by a one-ounce weight at a radius of 1-in. from the axis of rotation. The usefulness of the ounce inch as a unit of measurement is apparent in the next diagram (Fig. 3), in which a rotating disc is represented to which a five-ounce weight H has been attached at a distance of 2-ins. from the axis O. The unbalance in this disc will then be five times two, or ten-ounce inches, which unbalance can be corrected by mounting on the face of the disc along the line AO at any convenient distance from the axis O a weight which will produce a counteracting unbalance of ten-ounce inches. Thus in the second figure a weight W of 2.5 ounces has been put on at a radius of 4-ins. from the axis O, which provides a counterweight of 10-ounce inches directly opposite to the unbalance produced by H and hence the disc, if of thin section and homogeneous, is in perfect balance.

Now if the thickness of this disc be increased until it becomes a cylinder as shown in Fig. 4, and if the correction weight W be applied diametrically opposite H but on the opposite end of the cylinder, the cylinder would be in static balance but would still vibrate badly when rotated as there would be a dynamic couple produced by the 10 ounce inch unbalance located at either end of the cylinder.

The man in the shop frequently distinguishes static unbalance by the fact that the part will always roll on parallel bars until the heavy point is down. The trade generally assumes that dynamic unbalance is any unbalance which will evidence itself through vibration when the part is rotated. Technically, static unbalance is the single resultant centrifugal force which would be present in the body under rotation while dynamic unbalance is the resultant centrifugal couple present in the rotating body. It is interesting to note that static unbalance may be corrected by adding a single weight to the part balanced, while in order to obtain dynamic balance two weights in transverse planes some distance apart must be added to the part as shown in Fig. 4.

The static balancer is for balancing parts which are essentially discs, that is, bodies with little axial length. The dynamic balancer is required for balancing parts having any considerable axial length. It is difficult to specify what axial length may be used as a dividing line to separate work suitable for the static balancer from work suitable for the dynamic balancer. The speed at which the part runs, the rigidity of the structure carrying the part to be balanced and the points where correction can be made have considerable influence in determining whether a part requires static or dynamic balance.

The following is a table giving the maximum axial length of parts for satisfactory results in static balance for various speeds of rotation.

At	500 r.p.m.	...	6	inches	maximum	axial	length.
,,	1,500 ,,	...	4½	,,	,,	,,	,,
,,	2,500 ,,	...	3½	,,	,,	,,	,,
,,	3,500 ,,	...	2	,,	,,	,,	,,

If the structure carrying the part to be balanced, is weak, it is essential that parts for static balancing fall well under the limits of speed and maximum axial length just specified. In order that balancing can be satisfactory it is essential that the parts are sufficiently rigid that they will not distort in operation.

Static Balancing Machines.

Machines for giving static balance were the first type of equipment to be used by manufacturers, and the simple arrangement of parallel bars or knife edges known as standing ways was the first device developed for static balancing. When the object to be balanced is placed on top of the parallel horizontal members, gravity will cause the heavy side of the object to seek a position vertically below its axis. Metal is then added or removed by a cut and try method until the part to be balanced shows no tendency to roll regardless of the position it which it is placed. It is apparent that the accuracy of this system of balancing is dependent upon the two parallel surfaces being absolutely level and perfectly smooth and, even under the best

conditions obtainable, there will be enough rolling friction to prevent the heavy side of the part from assuming a true downward position.

To eliminate the necessity of keeping the knife edges perfectly level, the so-called balancing rolls were introduced. This machine consists of two pairs of rolls which carry the part to be balanced but although the use of rollers in place of the flat ways obviates the necessity for keeping the machine level, the friction of the rollers on their studs gives a source of error which is not present in the simple knife edge machine or standing ways and hence the roller type can only be used for very rough work.

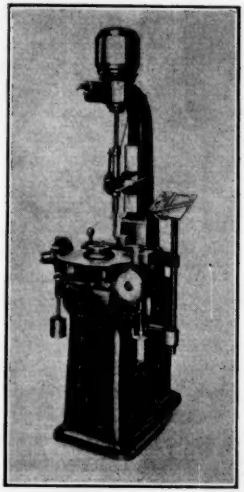
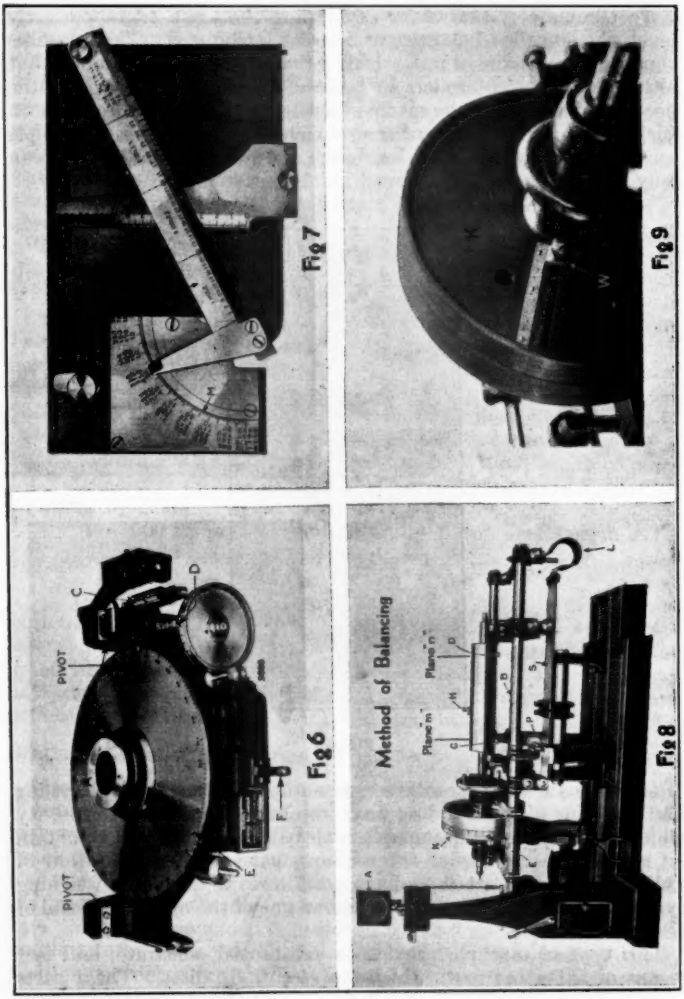


Fig. 5.

To eliminate the necessity for constant attention to the levelling and surfacing of the standing ways, to obtain a degree of sensitivity which is inherently unobtainable with balancing rolls and to obtain an accurate indication of the amount, as well as the position of unbalance, various attempts have been made to develop a weighing type of static balancer and Fig. 5 shows one of the most successful of these.

This type of machine provides a substantial, accurate, and fast means of balancing parts which are essentially discs. These parts include automotive flywheels, clutches, centrifugal pump impellers, single throw crankshafts for radial motors, couplings, narrow faced


PIVOT
C
D
PIVOT
E
F
Fig 6
Fig 7
Method of Balancing
Plane "m"
Plane "n"
Fig 8
Fig 9

pulleys, automobile road wheels, tyres and brake drums, torsional vibration dampeners for automobile crankshafts, and low speed narrow faced armatures for electric motors.

In this machine the work is carried on a vertical spindle in a cradle suspended on flexible pivots and the moment of the unbalance in the work with respect to a horizontal axis is measured by weighing in two positions 90° apart. (See Fig. 6).

In detail the operation of the machine is as follows : The part to be balanced is mounted with its axis in a vertical position on an adapter carried on the spindle *A*, which in turn is carried on a cradle suspended from two special pivots, allowing the device with the work mounted upon it to rock in one plane only.

The unbalance in the piece throws the cradle out of level, which is indicated on the spirit level *C*. This out-of-level condition is corrected by turning the weighing dial *D* until the bubble in the level is central. The reading of the weighing dial is then noted and the vertical scale *G* of the cutmeter is then set so that this reading of the dial *D* is indicated on the horizontal scale *H*. (See Fig. 7). The circular table *E* with the part still mounted on it is then turned 90° and in this position the bubble in the level *C* is again brought to a central position by proper manipulation of the weighing dial *D*. (Fig. 6). The protractor scale *K* is then moved until the second reading from the dial *D* is intersected on the vertical scale *G*. The point where the protractor scale *K* is intercepted by the vertical scale *G* indicates the amount of correction required to bring the piece to balance while the short arm of the scale *K* indicates on the graduated quadrant *M* the angular position of the unbalance. The table *E* is then turned to the angular position indicated on *M*, the work being balanced of course turning with it and with the table locked in this position the correction is drilled according to the depth and number of holes shown on protractor scale *K*.

After the correction has been drilled in the piece, the work may be checked if desired before removing from the machine and if the proper correction has been made the bubble in the level *C* will remain central at whatever poistion table *E* may be turned.

Dynamic Balancers.

While extreme accuracy of static balance is obtainable with the best of the weighing or gravity type of static balancing machines, this will not ensure smooth running of fast rotating parts which have considerable axial length since in static balancing only a single resultant centrifugal force is removed from the resultant of all unbalanced centrifugal forces in the body and there may still remain a resultant centrifugal couple. For a considerable period of time this couple could be eliminated only by trial and error methods after the unbalanced part had been assembled and was in operation. Finally,

however, a marking type of dynamic balancer was introduced of the flexible running test stand type.

In such a machine, the part to be balanced was carried on the end bearings in flexible supports and was driven by a narrow belt. The flexible end bearings were in some cases leather or steel loops suspended from the ceiling, or, alternatively, the design may take the form of rollers or plain half bearings for both ends of the part mounted on simple uprights which afforded ample flexibility.

The ends of the part to be balanced were coated with a thin film of Prussian blue, magnesium carbonate, or any similar substance. Then the part was rotated until it showed a considerable vibration and a stylus was brought up against the coated surfaces. From the length of the line that was scribed and the position of the line, the operator attempted to determine the angular position of the unbalance and the magnitude of the correction which must be made to provide a satisfactory dynamic balance.

This method of balancing was extremely slow and dependent entirely upon the skill of the operator. One of the troubles that the operator had with this device was to determine the position of the unbalance from the position of the scribed lines as the phase relationship of the vibration with respect to the position of the unbalance changes materially at different rotating speeds and also the magnitude of the vibration for different ratios of speeds of rotation to the critical speed of the system varies greatly. Thus although an operator could become somewhat proficient after extensive experience in balancing parts that were much alike, the human element was always a major factor in the equation and the process at best was one of "cut and try."

There are other objectionable features about this machine which unfortunately also appear in many other later and much more elaborate designs that have been brought out for dynamic balancing. One obvious disadvantage lies in the fact that the measurement of the resultant forces of the unbalance at both ends of the shaft is made in the planes of the supporting bearings or at the extreme ends of the part but neither of these planes could be used as the plane in which necessary corrections could be applied. It is, therefore, necessary to convert the reading from such a machine taken at the "plane of measurement" to proper reading at the "plane of correction," which is impossible to do with more than an approximate accuracy and, even though it were possible properly to compute the exact angle and amount of unbalance in the plane of correction from the indication of the machine at the plane of measurement, it is not possible to secure very accurate dynamic balancing without repeated readings since with this system even after correction is applied at one end of the part, there will still be vibration in both of the supporting members since these are not exactly in the plane of correction. As

this point is very important I will deal with it in more detail at a later stage in this paper.

Attainment of the highest possible accuracy is also defeated by the fact that the work is rotated under power during the time that readings are taken. As no source of power gives a perfectly constant speed, errors were introduced into the machine readings because of the wide fluctuation in the phase angle of the unbalance and magnitude of oscillation with comparatively small changes in speed as previously noted, and also because even comparatively slight speed fluctuations cause vibration of the machine's frame and work piece and other vibrations come from the irregularities in the driving belt all of which introduce disturbing effects which interfere with the determination of the exact unbalance in the piece being tested.

The inertia type of balancing machine, shown in Fig. 8, provides for the measurement of unbalance in the planes in which the corrections are to be made and is also free from any inaccuracies which may come from the driving motor as the machine and the parts being balanced are rotating freely, under their own momentum only, when the readings are taken and there is no contact with the motor drive at all. The principles involved in balancing with this machine may be very simply demonstrated with the very simple form of cylinder shown in this illustration, in which the two planes m and n located near the ends of the cylinder indicate the planes in which corrections are to be made.

The heavy spot H may be assumed to be anywhere in this piece. The shape of the body has, for the sake of simplicity, been shown as a cylinder, but, no matter what its form may be, the effect of the unbalance in a piece of differing sections and contours can all be combined into two resultant unbalances, so the application is theoretically the same, no matter what the shape may be.

To measure the unbalance in this cylinder, it is mounted in this balancing machine on the two adjustable pairs of rollers which are carried on the frame B. This frame also carries the headstock E and rests on two pivots P. The frame, with its pivots, resembles the familiar type of scale beam used in "even balance" scales. It is flexibly held in a horizontal position by means of the long flat spring S, which is fastened rigidly at one end to the heavy base of the machine and at the other end is attached to the outer end of the pivoted frame by means of the link L.

The headstock E is in two parts, these being arranged so that disc K can be turned angularly to any desired position with respect to the rest of the headstock. This disc is provided with a radial slot in which the sliding weight W (Fig. 9), may be clamped in any desired location. There is a graduated vernier scale along the slot so that the weight can be moved the desired distance very accurately. The sliding weight must have a known weight which is exactly 10 ounces.

The headstock with its adaptor and disc mounted thereon is in a state of perfect balance when the sliding vernier is at the zero mark on the scale and by moving the weight out a definite number of inches along this scale, the disc K may be unbalanced any desired amount measured in ounce inch units as shown in Fig. 9.

The frame, loaded with its headstock and the part to be tested, is free to swing on the pivots like a scale beam. Therefore, with the part and spindle at rest (not rotating) the frame will, when given an impulse oscillate up and down with regular beats, the time of which is constant and independent of the amplitude of the swing (just as in the case of a clock pendulum). The length of time for a complete oscillation under the above conditions is called the " natural period " of the frame.

When the part being tested rotates at a speed such that the time for one revolution exactly equals the " natural period " of the frame, it is said to be rotating at the " critical speed." In operating the machine, the cylinder is started at a speed slightly higher than the " critical speed," after which the friction pulley which drives the flywheel is lowered and rotation of the spindle and the work being balanced continues under their own inertia, the speed gradually diminishing to the point where rotation is at the " critical speed."

Because of the unbalance existing in the part, its rotation caused the frame to oscillate on the pivots. By watching the amplimeter needle move across the scale as the rotation continues, the amplitude of oscillation will be observed to increase as the speed of rotation decreases, and will continue to increase until the " critical speed " is reached when a maximum reading will be recorded. This maximum amplitude is proportional to the unbalance in the plane n and it is well to note here that this condition of synchronism can be repeatedly produced and hence the motion of the machine frame at its critical speed is always a direct measure of the unbalance in the work.

After determining the amount of unbalance in the correction plane n, the sliding vernier counterweight is moved out to a point which will produce the same ounce inches of unbalance in the headstock as were found in the correction plane n and with the weight out in this position the machine is again given a spin and another reading is taken. Dividing the first reading by the second by means of the slide rule conveniently mounted below the amplimeter gives a direct reading of the angular position of the unbalance on the lower scale of the slide rule and if the correction disc be unclamped and moved around to the angular setting thus established and the machine is again brought up to speed it will be found that there is no oscillation of the frame as the unbalance in the correction plane n of the work piece is exactly counterbalanced by the effect of the sliding weight in the headstock.

It will be noticed that the rollers supporting the part to be

balanced are adjustable and hence this machine is set up so that one of the correction planes *m* passes directly through the line of the pivots *P*. The other plane *n* is the one in which the unbalance is being measured and the unbalance in the plane *n* will be separately and accurately measured with no disturbance whatever from any unbalance that may occur in plane *m* since this is directly in the line of the pivots and will have no effect on the equilibrium of the frame.

The unbalance remaining in the piece after correction has been made in plane *n*, must be corrected in the other arbitrarily selected correction plane *m*. This is done by turning the piece end for end in the machine so that plane *m* will be removed from the neutral or pivotal part of the machine and the amount and angular position of the correction required in plane *m* are then determined in the manner already descr bed. When corrections have been made in both the planes *m* and *n* in accordance with the machine indications, the part will be in perfect static and dynamic balance

There is a further development of the same type of machine, but arranged with two amplimeters and two sets of pivots which may be alternately fixed or released so that in large scale production the same machine without change in set up or rehandling the piece to turn it end for end can be used to determine very quickly the unbalance in both correction planes.

The Fallacy of Dynamically Balancing in Planes other than the Planes of Correction.

A number of balancing machines have been constructed where the part to be balanced is carried in bearings which in turn are mounted on flexible supports of one sort or another. To measure unbalance in machines of this class, one of the flexible supports is locked while the unbalance in the end of the piece farthest removed from the locked support, is measured by the vibration of the unlocked support. The unbalance in the other end of the piece is measured by reversing the condition of the support.

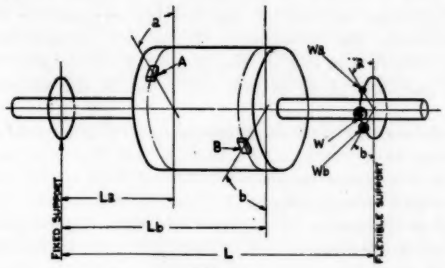


Fig. 10.

Fig. 10 shows a cylindrical part which is out of balance due to weights *A* and *B* which are in the two planes in the part in which it is permissible to make corrections. These unbalances are respectively at angles *a* and *b* from the vertical. In this case, the fixed and flexible supports are arranged so as to measure the unbalance in what may be termed the *B* end of the part. *La* and *Lb* and *L*, respectively, represent the distances of unbalance *A*, unbalance *B* and the flexible support from the fixed support or pivotal point. By reference to Figs. 10 and 11 the amount of the unbalance *Wb* in the plane of the flexible support which will cause the same motion of the flexible support as is caused by unbalance *B*, can be determined.

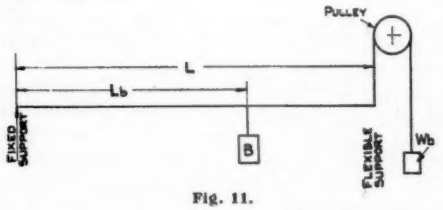


Fig. 11.

In Fig. 11 the system is shown as a simple lever where *B* is a weight pulling downward on the beam and *Wb* is an upward pull on the beam through the medium of a rope and pulley. From the laws of a lever we can find that :

Wb times *L* equals *B* times *Lb*, or

Wb equals *B* times *Lb* divided by *L*. (See Fig. 10)

In a similar manner :

Wa equals *A* times *La* divided by *L*.

Thus we find that unbalances in the two planes of correction affect the flexible support and are therefore, measured as unbalance in the end of the work adjacent to the flexible support.

Now *Wa* and *Wb* may be replaced by a single weight *W* which will cause the same motion of the flexible support as *Wa* and *Wb* cause. Obviously the unbalance *W* is not proportional to the unbalance *B* which is in one of the planes of correction, and further, the angular position of *W* is not the same as the angular position of *B*.

An example may help to show the error in this type of equipment. Let us assume that :

A is 4 ounce inches,
B is 2 ounce inches,
L is 15 inches,
La is 5 inches,
Lb is 10 inches.

then :

Wa equals 4 × 5 divided by 15 equals 1.33,
Wb equals 2 × 10 divided by 15 equals 1.33,

and if *A* and *B* are 90° apart angularly, *W* will be 1.875 instead of 1.33 which is a measure of unbalance *B* and its angular position will be midway between the angular position of *A* and *B* instead of being in line with *B*.

Now, in the example above, let us assume that *A* and *B* are 180° apart angularly. Then, *Wa* will counteract *Wb* as these unbalances will be opposite and of equal amount. In this case the flexible support will show that there is no unbalance in the *B* end of the work, yet, in the example, the *B* end of the work was two ounce inches out of balance.

Designing for the Balancing Operation.

In order that the modern balancing machine may be used to advantage, it is essential that the part be properly designed to facilitate the balancing operation and the application of the necessary correction to the part in order to place it in proper balance. Since dynamic balance is obtained practically always by adding or removing metal from a definite point in each of two selected planes in the work, it is desirable in designing any part which is to be dynamically balanced to provide these two transverse planes in which corrections may be conveniently made. These correction planes are preferably placed as near the ends of the body of the work as possible, since the greater the distance between the planes of correction the smaller is the amount of correction for a given dynamic unbalance.

The designer should also provide a method of applying the correction in these planes which will make possible the easy, quick, and definite removal or addition of the exact amount of weight required to give balance. A correction method which is not definite or requires great skill on the part of the operator, fails to make the greatest use of the exact indication given by the modern balancing machine. Of all methods of removing metal for balance, drilling seems to provide the most definite and easy method by which a desired weight of metal may be removed. However, metal may also be removed for correction by milling, turning, shaping, or grinding.

However, there are certain types of parts in which it is impossible to provide an excess of metal in any two planes, from which weight may be removed to give balance, and it is then necessary to make the required corrections by adding weight to the light side rather than removing weight from the heavy side. In such cases, the most practical method of applying weight for balance is by the use of the required length of a given size of bar stock, although metal is also

often added for balance in the shape of cast iron lugs, steel washers, or solder.

Frequently the shape of the work is such that in any transverse plane the radius at which corrections may be made is large enough only in certain rather limited sectors. This is the case in crankshafts, some types of fans and other irregularly shaped parts. In such parts it is then necessary to make component corrections, that is to make two corrections, wherever they can be made of such magnitude as to make their combined effect the same as a single correction made in line with the unbalance. This can be done with satisfactory accuracy, although it is somewhat undesirable from the standpoint of economy as it obviously takes twice as long to make two component corrections as a single correction and hence in many irregularly shaped pieces such as crankshafts, it is often more expedient to purposely throw or control the unbalance within certain angles where corrections may be made with the greatest convenience, as for instance, in the end crank cheeks or counter weights.

Conclusion.

In closing, may we simply remind you that vibration, perhaps the greatest enemy of modern, efficient, high-speed machinery, may be practically conquered in machines which have been properly designed so as to eliminate the vibrations due to critical speed, torsional oscillation, reciprocating and oscillating forces, and with proper static and dynamic balancing of their principal rotating parts. With this co-operation between the engineers, machine designers, and the manufacturers of balancing equipment, we will then have more efficient, smooth-running machines which will function properly with long machine life and a minimum power consumption. Bear in mind, too, that machinery with these desirable characteristics can usually actually be produced at a lower cost than can the inferior machinery with unbalanced parts.

Discussion.

MR. G. H. HALES (Section President), who presided, expressed regret that Mr. Senger was not present to share with Mr. Addleton the appreciation with which members of the Institution of Production Engineers had received their paper on the subject of Static and Dynamic Balancing. Mr. Addleton had prefaced his paper by remarking that as regards his personal part in its preparation, he himself felt in the position of "The tail that wagged the Dog." Perhaps it would not be inappropriate to reply to this remark in "Cricket" language, at a time when the English cricketers were battling in the Test match with Australia, and say, "What a Tail!" for Mr. Addleton had wagged to some purpose.

Before declaring the discussion open he would like to read a letter received from one of the members of Council, Mr. S. Gilbert, who had had an opportunity of perusing the paper but was unable to be present that evening. Mr. Gilbert wrote as follows: "I have read the paper on 'Dynamic Balancing' with a very great deal of interest and can find very little to criticise in the remarks made and the conclusions arrived at by the authors. I would say, however, that as regards the question of designing crankshafts for balancing, probably the best method—from a production point of view—is for the crank webs, which are taken as the planes of correction to be made circular. In this connection I would call the attention of the machine tool trade generally to the gross misnomer used in describing dynamic unbalance indicators as balancing machines. Heaven save the term! The usual practice is to put the part in an unbalance indicator, to turn it end from end at least once and then place it in some machine capable of removing metal. On the basis of what my American friends generally call "By guess and by God," and then again replace the piece in the dynamic unbalance indicating equipment to demonstrate just exactly how accurate the guess has been. Surely to goodness some capable machine designer can give the harassed production engineer one single production unit capable of both indicating unbalance and correcting it. With regard to the author's remarks on the fallacy of dynamically balancing in planes, other than the planes of correction. We built an unbalance indicator of sorts at Vauxhall Motors which most amply demonstrated this, and when we proceeded to put the pivots at each end under the planes of correction of the mass, we reduced the time taken to approximately Dynamically balance a crankshaft by 75 per cent. of the previous total."

MR. ADDLETON: With reference to Mr. Gilbert's letter on the subject of dynamic balancing, I most heartily agree with his suggestion that the crank webs, which are taken as the planes of correction,

should be made circular, as this would enable corrections for unbalance to be made at whatever angle this unbalance was in, and would also eliminate what Mr. Gilbert's American friends call " By guess or by God " in removing the necessary amount of metal for correction, for it would then be a simple process to drill a hole in this web to the correct depth and at the proper angle.

In regard to Mr. Gilbert's demand for a single production unit for indicating unbalance and correcting it, this is general practice with modern static balancing machines, but with dynamic balancing machines, the difficulties to be overcome before such a machine can be made are very numerous. I have seen examples of a dynamic balancing machine working in a production line where the balancing machine has been equipped with another machine to remove the metal for correction without removing the part from the balancing machine, but this can only be done when the shape of the part to be balanced lends itself to this procedure. We must not lose sight of the fact that a balancing machine is essentially a delicate weighing machine and without losing its very necessary sensitivity, cannot be built sufficiently rigid to act as a balancing machine and a drill press, milling machine or grinding machine. We would have a very bad opinion of our local butcher if, when we went to purchase our meat, he proceeded to place the joint on the weighing scales and chopped off the piece to the size we wanted with the cleaver while is was still resting on the scales and then weighed the piece. We should not have a great deal of faith in the correctness of his scales and would probably quickly transfer our patronage elsewhere.

Mr. E. J. H. Jones (Member of Council) : The subject to which we have listened this evening is one which I am convinced that we, as a body, will have to study far more in the future than has been necessary in the past. Not only have speeds increased in the automobile industry, but in almost all others and if the progress in this direction is as great during the ensuing years as it has been during the last ten then it looks like becoming one of the most important among our responsibilities. It seems that even with the best balancing machinery, the only object in perfect balance at all speeds, is one which is perfectly regular in form, runs dead true, and the mass is homogeneous or evenly distributed, and, therefore, requires no balancing. Suppose, for instance, we balance a shaft at the balancing machine's critical speed, at which speed the greatest amount of unbalance is registered, and we add weight at two defined planes to effect balance, we are not balancing dynamically opposite to the unbalanced forces in the shaft. We thereby create couples which must obviously produce strains at higher speeds, creating out of balance. So that even after balancing on a machine to within very fine limits, when the shaft is running at perhaps 20 times this speed, we must still have considerable unbalance forces. I should like to

have the lecturer's comments on this. I can well anticipate that in the future we shall be given many parts to balance, with which we shall experience considerable difficulty, and we shall have to insist that the designer has taken care that the whirling speeds of revolving parts do not coincide with the speed at which they are expected to run. The subject, however, does not end even here. The design must have been so arranged that there is no synchronisation between the whirling speed of the revolving and other functions of the mechanism, creating harmonic vibration and tending to nullify our efforts at balancing.

MR. ADDLETON: Mr. Jones has brought up a very interesting question in regard to dynamic balance. We obviously do create small couples along the piece by correcting for unbalance in two planes only. Unbalance in a part is caused by lack of homogeneity in the metal of which the part is made or the irregular shape of the part due to errors in machining or the part not being machined. This lack of homogeneity or lack of uniformity, due to machining errors may be anywhere along the length of the part or at any angle around its circumference, and there may be any number of these. The balancing machine sums up all of these errors into one amount and gives you the angle at which this unbalance amount works, so that when we correct the part we nullify the effect that this gives in vibration when the part is rotating. To go farther, do these small couples give us any effect when the part is rotating? We will take a plain cylindrical shaft as an example and what is true about a plain cylindrical shaft is true about any irregular-shaped part. All shafts are held in two or more bearings, but we need take into consideration only the two end bearings as all the others are merely supports to prevent sag in the shaft or to take care of external forces applied to the shaft such as in the case of the crankshaft of a motor. The effect of any unbalance in a shaft when it is rotating is to cause it to try and turn end for end, with a change of direction in this movement every half rotation of the shaft. Therefore, if we sum up the total of all our small unbalances in the length of the shaft, and obtain the mean angle of the angles of these unbalances, and make a correction of the sum of these unbalances at this mean angle as near the end of the shaft as possible, we neutralise the effect of all these unbalances, and so prevent the shaft trying to turn end for end—which is the cause of vibration and excessive wear on the bearings, and therefore proves we do not need to worry about any small couples we place in the shaft by correcting only in two planes.

The modern balancing machine works to very fine limits indeed and with care in its operation a part can be balanced as accurately as is humanly possible and as a part balanced at one speed is balanced at all speeds, providing it is sufficiently rigid to keep the

same shape or form we need not worry about the speed we run the part at.

MR. M. F. COHEN : The reply given to the last speaker by the lecturer seems to me to be, in part, a little misleading. Does the lecturer intend to convey that after balancing an automobile crankshaft in two planes, that is, at the two extreme bearings, forces still remain in the shaft when it is rotating and resting on *all* its bearings, which should be taken into account ? If that be so, how does the lecturer suggest balancing out those forces ?

MR. ADDLETON : Mr. Cohen's comment leads me to think that I did not make my reply to Mr. Jones very clear. We must first fix in our mind that any rotating shaft only needs two bearings to carry it, as near the ends of the shaft as possible and only on these two bearings the effect of dynamical unbalance operates. In common practice other bearings are placed between these two, as the tendency towards reducing weight reduces the strength and rigidity of the shaft and it must be supported in the centre and in the case of the crankshaft these centre bearings take the thrust of the power applied and the change in direction of the reciprocating parts. This is the only work these centre bearings have to do. The whole of the disastrous effect of unbalance in the shaft affects only the two end bearings, therefore, if we correct in two planes as near these two end bearings as possible, we nullify all the objectionable forces that unbalance causes, and at the same time simplify our methods of correction.

MR. C. C. FERGUSON (Member of Council) : The authors seem to have limited their paper to automobile practice. I would have liked it amplified to include illustrations of other work. Perhaps Mr. Addleton could tell us about balancing a long shaft with pulleys and how to get over the different stresses set up owing to the different sizes of pulleys and the intermittent work on the shaft caused through different machine tools being operated at the same time, especially in connection with machine tools running at very high speeds.

MR. ADDLETON : Although the slides I have shown were practically all of plain shafts in order to simplify the explanations, the tendency of the discussion is towards automobile practice, but I hope Mr. Ferguson will appreciate that what I have said about crankshafts will apply also to shafts with pulleys. With a long shaft carrying a number of pulleys, it is very necessary to balance the pulleys separately, and then the shaft must be balanced, after which when all are assembled together, the whole will run in perfect balance and providing the assembly has been correctly designed with sufficient support and strength, the effect of stopping and starting high speed machine tools will cause no unbalance in the shaft or pulleys.

MR. V. GARTSIDE: Is any means provided on the balancing machine that was illustrated for finding the location of the planes in which the corrections necessary should be made in order to balance the article being tested? Mr. Ferguson had referred to the question of balancing a shaft with a number of pulleys. In dealing with similar shafts in connection with drives to woodworking machines where high speeds have to be dealt with, it is customary to balance each pulley separately. The pulleys are first balanced statically on the usual parallel ways set level, wide pulleys are then given what is called a running balance, which is equal to dynamic balancing. On a wide pulley it is necessary to find the point on the width where the counter weight has to be fixed, otherwise a wobble would be set up when running at speed. This point would be in a plane similar to what has been referred to, which was at right angles to the axis. The machine for testing the running balance has a vertical spindle with a pivot on which a plug rests, which is held in the bore of the pulley with a flat key, and drivers for driving the pulley by the arms. Having obtained the amount that the pulley is out of balance statically by a piece of clay, after running the pulley, the clay is moved across the inside of the pulley rim until all the wobble disappears and at this point the permanent balance weight is fixed, this weight being the same as that of the clay. Although this method may appear somewhat crude compared with the methods described by the author, it proved quite effective and embodied some of the same principles.

MR. ADDLETON: No means are provided on the balancing machine for finding the plane at which to correct, for this is not necessary. Any points along the shaft can be chosen, but these should be as near the ends as possible, and where it is possible or permissible, to apply or remove metal to make the correction. This is a point where the designer can assist the production department considerably, by designing the component with a view to simplifying balancing—by making provision for correction points near the ends. Mr. Gartside's description of the methods used to balance pulleys is very interesting and undoubtedly with an experienced man, with unlimited time, a fairly close approximation of balance could be obtained, but it cannot be compared with the modern machine where mathematical accuracy can be obtained with regularity by semi-skilled labour.

MR. K. V. WEBSTER: In the examples given to illustrate the method of balancing, critical speeds have been mentioned. In the case of a crankshaft it has been stated that in obtaining balance by adding or removing metal at the end, certain other minor unbalances were introduced. If one obtained balance at one speed, i.e., the critical speed, was it not a fact that one had unbalance at

other speeds as, of course, in the motor car crankshaft the working speed was actually a wide range of speeds.

MR. ADDLETON : Mr. Webster will remember that in my paper I read in reference to the " critical speed " as follows : " At such speeds any design of shaft will become dynamically unstable and vibrations of considerable magnitude are likely to develop." Then later, I read : " Vibrations from this source can only be eliminated by proper design." Therefore, a crankshaft can be in balance and a motor car run smoothly over its full range of speeds with the exception of this " critical speed." The designer must therefore take care in his design to have this " critical speed " at a point where it is least objectionable.

MR. D. PISTOR : Does the lecturer consider that in the case of small electric motors, such as those used in vacuum cleaners, where the fan is mounted on the armature shaft extension, the correct procedure when balancing is to dynamically balance the armature and statically balance the fan separately, or whether it is better to dynamically balance the fan also, either on its own armature or on a mandrel ?

MR. ADDLETON : With reference to Mr. Pistor's question of dynamically balancing a fan for vacuum cleaners. In the table I gave you of the approximate maximum axial length of parts that could be satisfactorily balanced statically, if this fan comes within that range, it should be balanced statically. I always advocate that each part of an assembly should be balanced separately, for with the accuracy obtained on modern balancing machines, the completed assembly will be in perfect balance. By balancing separately, the assembling of the components is often simplified and no difficulty is met in the question of replacement of any one part of the assembly.

A VISITOR asked if it would be possible to balance a turbine motor after the assembly of all blades.

MR. ADDLETON replied that it was impossible for anything to stay in balance if it did not keep its shape when running.

MR. FERGUSON : Has the author had any experience in balancing marine propeller shafts ? Members who have had experience in reciprocating marine engines have very often been up against difficulties in connection with the " racing " of propeller shafts, and if any information could be given as to the nature of the stresses and strains set up in the shaft on such occasions, especially on the thrust collars, it would be of value.

MR. ADDLETON : A marine propeller shaft if in balance is not affected by " racing " from the point of view of unbalance effect. I am sorry but I have not any information on the subject of the stresses and strains on the shaft or thrust collars caused by " racing."

MR. L. BEADLE : In the case of a shaft that has been balanced in

a true horizontal plane, is it possible to balance this when operated on an inclined plane ?

MR. ADDLETON : A shaft balanced in a horizontal plane is in balance when operated on an inclined plane.

MR. BAMFORD asked a question about the effect of using unbalanced parts on machine tools that had themselves been properly balanced.

MR. ADDLETON : The effect of machining an unbalanced part on a rotating machine tool will be that the part will be machined out of round, therefore a counter-weight should always be applied to neutralise the effect of this unbalance.

MR. B. H. DYSON : I would like to take the opportunity of substantiating the lecturer's remarks on the balancing machine as an aid to the production engineer. About two years ago I had experience of the difficulty involved in balancing metal air screws. Although the propellers were accurately machined and the twist and profile were checked to gauges and then balanced on knife edges, trouble arose from the marked difference in performance that was noted when aircraft were fitted with alternative propellers. It was decided to instal a dynamic balancing machine. As it was out of the question to make the necessary corrections by drilling holes in the blades, the trouble was overcome by machining a groove round the hub and fixing the required weights in the groove in the positions indicated by the balancing machine. After the initial " teething " troubles had been overcome—I understand that our machine was the first used in this country—the production time for balancing was reduced from $1\frac{1}{2}$ or two hours by the old methods to twenty or thirty minutes by the balancing machine. Also, a marked increase in the performance of aircraft fitted with dynamically balanced air screws was consistently obtained.

MR. W. G. CARR : Is there any definite point in diameters in relation to the axial length where it could be determined whether static or dynamic balancing should be employed ? Some years ago I had experience of the manufacture of electric motors, fans, etc., where it was stipulated that the fans had to be absolutely quiet when running. The armatures were balanced on knife edges or rollers, as described in the lecture. It was unbelievable the noise that was created by what seemed to us a small amount of unbalance. In addition to mechanical vibration it had the effect of setting up what was termed an electrical noise. Many methods were employed, such as boring the fields a few thousandths larger, staggering the armature laminations, etc., but there was probably a great deal of luck attached to the results obtained. Had a more accurate balancing of the armature been carried out it would have obviated many hours of " wangling " with individual motors, with consequent cheapening of production. As static and dynamic balancing will

undoubtedly be a large factor in future production, it seems that balancing machine capabilities will have to be much further extended, as the accurate balancing of some components will be sure to reveal unsuspected inaccuracies of balance in other directions. Here is a recent experience of the effects of unbalance. An emery wheel adaptor was made for a grinding machine. By some mistake the outside flange (measuring 5-ins. dia. × ¼-in. thick × ¾-in. bore) was bored out .025-in. too large. When mounted the different position this play allowed the flange to take caused the whole table and head of the machine to vibrate so much that it was impossible to use. With the usual adaptor this machine carries the same wheel and is quite successfully operated.

MR. ADDLETON : There is no definite point in diameters in relation to the axial length to determine whether static or dynamic balancing should be employed. Diameter does not affect the problem. The only points to be considered are revolutions per minute and axial length. The vibration and noise was undoubtedly caused by the armatures and fans not being accurately balanced and with the use of modern balancing machines this problem would not be met. I am in agreement with Mr. Carr that with the use of modern balancing machines, closer tolerances of fits will have to be maintained in order to obtain the full benefits of the accuracy of balancing machines.

MR. B. C. JENKINS : I wish to congratulate Mr. Addleton and his co-author on the production of a clear and concise paper on the subject of balancing, and to congratulate Mr. Addleton particularly on his frank admission that any job balanced on the apparatus he has described is only in true dynamic balance at the planes of correction. The importance of power-weight ratios in automobile design will undoubtedly continue to increase the usage of both static and dynamic balancing machines, especially the latter. Listening to the paper as read by Mr. Addleton, one must pay tribute to the older craftsmen for the way in which they produced such beautifully balanced mechanisms without any of the modern balancing equipment. We, as production engineers, should realise the debt of gratitude owing to the designers of such equipment and its effect on lightening the load of trouble on our shoulders.

MR. J. CALDERWOOD : Mr. Addleton has said that he prefers, where machinery is made up of several parts, to balance each separately. It would be of interest if he told us how he compensated for the keys and keyway in the balance of these parts separately. The lecturer has also said that he preferred to choose the planes in which he carried out the balancing as near as possible to the ends of the part to be balanced. This does not seem altogether sound, as he has agreed that balancing leaves in residual stresses due to the fact that the balance weights are not diametrically opposite to the

point of unbalance. Surely the best position to add the balance weights would be at a position one-quarter of the length of the part to be balanced from each end. This would on the average give the minimum residual bending stress on the part to be balanced. This suggestion, of course, does not apply to such parts as crankshafts, where there are in any case considerable bending stresses due to centrifugal force, but it does apply and might be of considerable importance in such parts as turbine rotors. Speaking of torsional vibration, the author has suggested that the best way of preventing this is by fitting a damping device. In another part of his paper, speaking about vibration generally, he has pointed out that damping absorbs a lot of power. Surely his recommendation for the fitting of dampers is not consistent with this other remark. As an instance of the power absorbed in damping I may mention a case where an approximate measurement was taken of this on a marine engine driving a propeller. This engine had a torsional critical speed at about 50 revolutions per minute. In the ordinary way, of course, the torque required to drive the propeller follows a speed squared law. In this instance the torque followed this curve fairly closely up to 45 revolutions per minute. Between there and 50 revolutions per minute the power absorbed rose very rapidly until, just below the critical speed, the torque that the engine was delivering was more than double that that could be absorbed by the propeller in the ordinary way. A little further increase in the engine power made it jump through the critical speed and speed up immediately to almost 80 revolutions per minute. The torque actually at the critical speed of 50 revolutions per minute corresponding to the normal torque at about 80 revolutions per minute. In slowing down the torque fell steadily along the normal curve to rather above 60 revolutions per minute. It there started to come above the curve and when the speed had been reduced to 58 revolutions per minute a slight further reduction in the fuel made it drop immediately to about 47 revolutions per minute. The damping in this case was, of course, provided by the propeller and the actual torsional vibration was a very heavy one, but similar, though possibly not so severe a phenomena, must certainly occur with the usual type of damping device. For this reason the only proper way of avoiding trouble from torsional vibration is either in the first case to make a calculation and keep the critical speed clear of the running speed, or if this has not, or cannot, be done, then the stiffness of the shafts must be altered if a torsional vibration is noted when the machine is running.

MR. ADDLETON : Mr. Calderwood has brought up the question of keys and keyways in components while being balanced. These can easily be taken care of by fitting in special half keys which fill up the keyway to the diameter of the shaft or bore during the balancing

operation. In regard to the point of correcting as near the ends as possible, the advantages obtained by reducing the amount of material to be added or removed to bring the shaft in balance and the fact that the two end bearings are the only ones to suffer from the question of unbalance prove that the correction planes should be as near the end as possible.

We should realise that balancing is not a cure for all our vibration troubles, for if the designer does not make the part sufficiently rigid to retain its shape and withstand the external forces applied to it, however accurately it is balanced we will still get vibration. If the part is correctly designed and then accurately balanced, the result will be a smooth running and efficient component.

With regard to dampers and the power they absorb, every case must be taken on its merits and the best compromise must be made. Where the power cost is the primary consideration, a certain amount of torsional vibration must be born, but where the power cost is secondary, effective damping can be used to eliminate this torsional vibration.

MR. GARTSIDE: Returning to the question of the position of the planes, this is no doubt very important. Take an eight-cylinder crankshaft and suppose you correct it for balance in the planes mentioned, could you get any " whip " in it and still show a balance ? Just one other point : Would a gyroscopic effect have any influence on balance ?

MR. ADDLETON: I think Mr. Gartside has exaggerated the importance of the position of the correction planes ; they should be as near the ends of the shaft in order to reduce the amount of metal to be added or removed to bring the shaft in balance. In the case of an eight-cylinder crankshaft corrected for balance, if the shaft is not sufficiently rigid or sufficiently supported in the centre it would " whip " and at that period would show an unbalance. A part is only in balance when it retains its shape. Any movement from its original shape tends to throw it out of balance.

MR. D. J. SCRIVEN: We have heard a great deal this evening about the balancing of crankshafts. We also know that the movement of a reciprocating part in a system, such as a piston, can be balanced by introducing another part of equal weight moving at an equal speed in an opposite direction. The connecting rod is the link between the reciprocating motion of the piston and the rotary motion of the crankshaft, and one end is therefore subject to the reciprocating forces of the piston, and the other to the centrifugal forces of the crankshaft. Can the connecting rod be balanced, taking these factors into consideration ?

MR. ADDLETON: The big ends of connecting rods are distributed equally around the crankshaft so with a fixture holding by the pin in the piston pin end, the big ends can be weighed and by having

all the big ends of the rods for each engine weighing the same, no unbalance effect is caused on the crankshaft. This balancing is carried a step further by weighing the whole of the connecting rod and the piston and having these weighing the same for all rods and pistons in each engine.

THE CHAIRMAN moved a hearty vote of thanks to Mr. Addleton and his co-author, and Mr. Addleton briefly replied.

THE ORGANISATION OF PRODUCTION ENGINEERING.

Paper Presented to the Institution, Luton and Glasgow Sections, by B. C. Jenkins, M.I.P.E.

PRELIMINARY investigation of this subject brings forward the necessity for a definition of the duties, aims, and ideals, of the production engineer. Many people would have us believe that the production engineer is something entirely new, merely a by-product of mass production methods of manufacture, without parallel in the more old-fashioned organisation. Even in factories which take pride in their high degree of efficiency and organisation one frequently finds strong opposition to the so-called interference of the production engineer and his staff.

Those of us who served our time in the old-fashioned engineering shops recognise that production engineering means in effect pre-planning, and that this is nothing new. It was carried out in the old days in a more or less efficient manner by the operative, foreman, superintendent, etc. When the foreman decided that he would give a certain job to Bill, who operated the horizontal miller, to carry out a given operation, and then passed it on to Jack, the driller, and Jim, the borer, and so on through a given sequence, he was pre-planning. When Bill, Jack, and Jim, decided how they would set up and clamp the job, and whether they would rough and finish, or finish in one cut, and determined the feeds and speeds they would use, they also were doing the same thing. So one could carry on simple illustrations throughout the organisation from the managing director down to the office boy. Accepting this as true, why, then, set up a new line of demarcation in industry? The answer, of course, is to carry out pre-planning on a more scientific basis than hitherto was possible, and so avoid the pitfalls which were constantly arising owing to the individual only taking into consideration that particular operation, or portion of an operation, with which he was most intimately concerned.

A simple instance which comes to the mind of the writer amply demonstrates the whole case for accurate pre-planning. In the early days of what the writer prefers to call organised production when unskilled labour was gradually being introduced to the machine shops, it was a custom for green labour to be put on roughing operations on important work. This roughing out was followed by

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the finishing operations, to fine limit, by skilled operators. A suggestion by the writer that limit gauges for the roughing operations be provided was turned down in disgust by the foreman, a highly skilled operator of the old school. He had always roughed out by the use of calipers and the rule, and found no difficulty in obtaining accurate size in finishing operations. He could not conceive that any serious re-action could arise in finishing due to badly varying rough turning.

Definition of Production Engineering.

A reasonable definition of production engineering is difficult to make as the status and ramifications of the production engineer vary in practically every plant, but it must be agreed that the duties of the production engineer commence with production, and production may truly be said to have commenced when design of the product has reached a reasonable stage of consolidation. The definition suggested by the writer is as follows :—

(1) Analysis of product with a view to reasonable modification for production purposes consistent with maintenance of all essential engineering specifications and requirements.
(2) Pre-planning of methods of production and operation sequence.
(3) Layout of plant to carry out such methods and sequence.
(4) Determination of machine tools and designing, making and proving of the most efficient equipment for producing a given product within the limitations set by quantity, quality and managerial policy.
(5) The setting up and maintenance of a recording system to supply information for any extension of the above activities.
(6) The maintenance and issue of all tools and equipment for production purposes.
(7) The maintenance of all production machinery.

The writer realises that this may appear incomplete to many of our friends and that such things as time study, material handling and production control might be added, but would state that the definition put forward is in his considered opinion one covering those activities which should be definitely within the province of the production engineer.

In certain cases the production engineer may be called upon in a consultative capacity to deal with the erection of a new plant on a site to be determined. The writer does not propose to deal with this phase of production engineering to any great extent, but it must be touched upon as most of us are faced from time to time with extensions to existing plants.

In choosing a site for the proposed factory the following major points should be considered :—

(1) Suitability of site for the particular type of product to be manufactured.
(2) Possibility of extensions of manufacturing areas from time to time.
(3) Position of site relative to sources of raw material supply and markets for finished product.
(4) Facilities available for transportation of both raw material and finished product.
(5) Supply of labour available within or adjacent to the area and its suitability for the class of manufacture about to be commenced.
(6) Supply of power, water, and fuel, and their prices relative to those prevailing in competitive areas.
(7) Drainage and sanitary facilities available.
(8) Rates and taxes prevailing within the area.

The type and layout of the factory will, of course, be largely determined by the product to be manufactured therein, but a few general remarks can be made. The first consideration from the angle of the production engineer is so to build and lay out the factory that the maximum amount of free flow of product be obtained from raw material to finished product, for it should be remembered that the primary basis upon which production engineering should be built is *flow of production*.

Raw materials should be received as close as possible to the point of consumption, and flow through the factory until absorbed in the finished product with a minimum of back tracking. Inter-operational transport must be considered, particularly the possibility of using gravity or mechanical conveyors. Fire risks should be taken into consideration, and so far as the general scheme will permit those areas in which fire risk is high should be segregated. Ample provision for fighting fire should be made in such areas, and as many points of vantage as possible arranged for and marked on plans. Provision for adequate lighting, heating, and ventilation must be made. With these few remarks the writer leaves this side of the business to the specialist and reverts to what may be regarded as the more legitimate side of production engineering.

Assuming that the design of product has reached that reasonable stage of consolidation referred to in an earlier paragraph, advance prints of component parts and also assembly prints should be obtainable from the engineering department. Parts and assemblies should be numbered for easy registration and identification, as the use of part names only is cumbrous and does not lend itself to systematic registration.

Analysis of Product.

Each component part should now be carefully analysed from a production point of view, reference being made to the assembly

print for the possibility of any suggested alteration being made without affecting the correct functioning of the assembled unit.

Points to be noted, particularly during such analysis, are :—

(1) Suitability of part for manufacture on existing machinery and/or equipment.
(2) The elimination, wherever possible, of the necessity for special purpose machinery, particularly where such machinery is of non-standard character and liable to be scrapped as unsaleable when part becomes obsolete.
(3) Clearances between mating parts should be carefully checked to see that proper fits are obtained.
(4) Tolerances should be checked so that maximum possible manufacturing tolerances are available consistent with maintenance of quality required. Thousands of parts are being made every day to .001-in. tolerance which might just as well be given .010-in. or more.
(5) Where non-standard dimensions are given for bores and screw threads the possibility of standardisation should be explored, as non-standard tools and gauges are more expensive than standard. Varying requirements from standard increase the inventory in spare tools and gauges, and stocks carried are usually much greater owing to the time required to get them made instead of being purchaseable over the counter. Parts of like nature can often be brought to one standard set of dimensions by a little forethought on the part of the designing engineer.
(6) During the analysis some thought should be given to the production methods to be adopted. For instance, the addition for machining purposes of lugs or bosses to castings and stampings should be considered, and if required, should be added to prints.
(7) Heat treatment requirements must be investigated as it may be necessary for parts to be carburised before certain dimensions are finish-turned, and the carburised surface to be removed from such dimensions before quenching. This may entail modification to stamping dimensions.
(8) Machining allowances on castings and stampings and draught angles allowable should be shown on component prints.

The above are only a few of the many points which arise during this process of analysis.

Commencement of Production Planning.

The authority to commence actual production planning of a particular part should be by means of an engineering release form together with material specification and approved component part print. These should reach planning engineer through record clerk

who should fill in blue print record card showing date of acceptance of engineering release and blue print, and file same in part number order in appropriate filing cabinet, thus forming record of all blue prints and releases received.

Planning engineer should have blue print and engineering release filed in the same manner. Engineering releases being filed in cabinet marked "*awaiting planning*," this forms a record which shows at a glance the load with which that section of the activity has to deal, and leads to a demand for increased help when heavy. Blue prints should be filed not in numerical order but in order of acceptance, and should be dealt with and planned in that order, exception being made in the case of extremely urgent parts, such parts being given priority. These remarks apply, of course, to what might be termed the every-day bread and butter jobs.

The introduction of a new model requires a different method of attack. In this case the planning is carried through in a predetermined order of priority laid down according to the time required to get machinery and equipment made and installed. In our own case we commence with engine, then gearbox, axles, steering, and frame parts, etc., body jigs and sheet metal dies, etc., being dealt with in parallel with engine by specialists in those activities.

Parts list of the various units are reduced to numerical order and charted, and are marked off on chart as they are planned to avoid any possiblity of even a bolt or nut being missed through any straying of engineering release or other accident.

Compilation of Routing sheet.

The compilation of routing sheets is the first active step in production planning and involves the following studies :—

(1) Most efficient method and sequence of operations.

(2) Method of location for castings and stampings.

(3) Equipment necessary to carry out sequence of operations.

(4) Availability of machinery in the divisions through which work is to be routed.

(5) Destination of completed part, i.e., sub-assembly or major assembly to which the part is to be routed.

The operation sequence can only be decided after an intensive study of the part with a view to seeing that such sequence will produce the part to the degree of accuracy and finish required. In many cases this involves a high degree of forethought and logical reasoning to decide the primary locating points for the first operation, and the production of the master locations from which all subsequent important operations will be located. Master locating points should be used throughout wherever possible and only changed at points where local accuracy is the main essential. These remarks

apply with particular force to castings and stampings, but also in greater or less degree to all classes of machined work.

The determination of primary locating points on castings and stampings should *never* be settled without reference to the foundry or the forge, as their production methods vary considerably, and it is rather annoying to find that the locating point you have chosen is just the point which the foundry has used for a riser, or that the stamper will not undertake to guarantee the accuracy of the point you have used. Wherever possible, locating points should be thrown up in such a manner that they can be dressed by the supplier to obtain the accuracy desired.

Selection of Machinery.

The selection of the machinery used for the various operations must, of course, largely depend upon the volume in which the product is to be put through the plant. Other factors being the cost of the ideal machine and equipment in the case of new machinery being required, and in the case of existing plant the availability of unused or partially used machine capacity even though the machinery in question be far from the ideal.

To check the machine capacity available within the plant it is necessary to keep machine loading sheets scrupulously up to date showing the load on each individual machine in every division. Shop layouts showing the site of every machine are also a vital necessity.

Take for example the case of a planning engineer planning to put a new cylinder block through on existing line of machinery which is in use on another block. He must first of all be able to check the capacity of the line to carry the additional load. Secondly to determine the exact relationship of one machine to another for position in the line, and the space available to inject any additional machinery required, and the amount of machine movement required to inject such a machine at the required point. The machine load sheets give the information for capacity. The shop layout plus small scale dummies of the machines enable him to determine the layout of his new line, and incidentally have a great bearing upon the working efficiency of the planning sequence. The shop layout is also used in the same manner when the injection of a new line of machinery becomes necessary.

Now let us take the case of a simple component which is produced by what we term section machinery, by which we mean machines used for a varying range of components which thread through the machines in batches, the same as in any ordinary jobbing shop. It is still necessary for these jobs to flow through these machines, so far as possible, without back tracking and to end up as close to the point of usage as possible. The planning engineer having laid out his pro-

posed sequence of operations, by reference to the shop layout and the machine load sheets, is enabled to determine the best machines for his purpose and calculated to give him the best order of flow possible under the circumstances. The machine numbers are added to the routing sheet, time estimates are made, and the load added to the machine load sheets. These times are, of course, revised where necessary when job is in production and accurate time study has been completed.

The importance of the *operation sequence* cannot be overstressed. It is the foundation stone upon which the whole edifice of production is built. The writer on one occasion heard one of the leading engineers of this country, a man of wide practical and technical experience state, " the production efficiency of any manufacturing organisation is in itself a measuring stick of the accuracy and efficiency of the initial planning of the job."

Errors in jig or tool design can be corrected, either by alteration or replacement, but errors in operation sequence may have such far reaching effect that a whole line of machinery jigs and tools are rendered totally inefficient, and become the measure of efficiency of the whole plant.

Issue of Equipment Instruction Sheets.

Routing sheet and operation sequence completed, the planning engineer now concentrates on the jig and tool requirements, reference to equipment records will enable him to check up on existing equipment and where found usable such equipment will be called for on instruction sheets. When no suitable equipment is available the details of equipment required should be entered upon the sheet. Description of requirements should be of the fullest nature, locating points should be given, general lines of design should be described and rough sketches made when necessary, methods of clamping should also be specified. Incidentally such instructions as are issued on these sheets should not be held as tying down the jig and tool designer rigidly, he should still have freedom to suggest alternative methods, or alteration to those laid down, but in no case should alteration be made without the consent of the planning engineer.

Issue of Tool Orders.

On completion instruction sheets together with routing sheet should be passed to records section for the typing of necessary tool orders and routing sheets. A separate order should be made out for each piece of equipment which requires design. These tool orders are made out in quadruple form in our own organisation and form the basis of a simple but effective tool progress system. Instruction sheets and tool orders are now passed to drawing office via progress man.

Designing of Equipment.

Equipment is designed using appropriate size of standard drawing sheet, the only authority for design being the issue of instruction sheet accompanied by tool orders.

Machine dimensions are checked by reference to standard machine data sheets and draughtsman checks for clearances, stroke, etc. It is also recognised as the duty of the draughtsman to check up for any necessary addition to the special tools enumerated, and also to check the standard tools asking for additions where necessary. It must be appreciated that until the complete scheme is laid out on the board one can never be certain as to detailed requirements in these directions. Completed drawings are checked by a competent checker before being passed for estimate of production cost.

Cost Estimates.

Each piece of equipment should be carefully checked for cost. In our own case we use standard forms for this purpose and each detail is broken down into turning, milling, boring, drilling hours, etc., plus material and pattern cost, overhead being added to the total. This method covers a dual purpose in our case. The detailed break down enables us to keep check of our load on tool room equipment when we make within the plant, and also enables us to get pretty keen prices when equipment is made outside. Checks are made on all completed orders and the measure of accuracy of estimate determined accordingly. It is generally found in our case that estimating errors on any batch of completed tool orders lie within 10 per cent. and a check made on approximately £20,000 of equipment show an overall estimating error of less than six per cent.

Issue of Purchase Requisitions and Work Orders, etc.

On completion of estimates, equipment tracings, instructions sheets, tool orders, and cost estimates are passed to records section via tool progress man. Purchase requisitions or tool room orders are now made out according to whether the equipment is to be made within the plant or purchased. In the case of purchase requisition this is preceded by request to purchasing department, to obtain tenders except in the case of standard articles purchased over the counter. The necessary blue prints are taken from the equipment tracing and tracing filed in equipment order number.

Operation equipment sheets are typed out from instruction sheet and blue prints taken off for issue to production departments as necessary. These equipment sheets give complete details of all equipment both standard or special required for the particular operation specified.

Tool stores master record card is also filled in for each piece of equipment used. These cards form a complete record of jobs for

which any piece of equipment is required. This is a vital necessity as when any part becomes obsolete, purchasing must cease, and unless equipment is required for further jobs, same is passed to obsolete parts manufacturing tool stores, or alternatively to surplus and idle stock for sale or scrap.

Manufacture of Equipment.

The general routine of a tool room is so well known as to require no description. In our case tool room is on day work basis job cards being issued for each job to operators through cost control clerk. This man is under the control of the accounts department, and clocks the operator both on and off each job as starting and completion of job. No operator can be in possession of two job cards at one and the same time, the new card only being issued on return of the old one. Job cards bear the serial number of the internal work order for the particular piece of equipment for which it is intended. Material requisitions are issued in the same way and carry the appropriate serial number. Job cards and material requisitions are the basis upon which final cost of equipment is determined.

Operators working upon maintenance work such as cutter grinding, hardening, etc., work on a weekly job card detailing the nature of the work upon which they are engaged.

Minor repairs to equipment which entail no structural alternations are carried out at the request of production divisions, and job cards issued giving the equipment number and charged to such divisions. Major repairs can only be carried out by the issue of internal work orders. Alterations to new equipment during demonstration are charged either to faulty manufacture of errors in design, and are chargeable to the planning department.

Inspection of Equipment.

Inspection of equipment should be carried out in a separate department whether made internally or purchased outside. The control of such a function must be in the hands of a really competent man who understands both tool manufacture and production requirements. The equipment provided in such a department should be adequate and of a really high quality, and should be maintained in that condition. Economy in this direction is false economy. Arguments between tool room or outside supplier and inspection department, are bound to occur and be the subject of doubt unless accuracy of equipment be above suspicion.

The writer appreciates the difficulties surrounding the works manager and the production engineer, who are both being pressed and are in turn pressing for economy in every direction, when asking for the continuous replacement of inspection equipment, but inaccurate inspection of equipment means inaccurate work and this will rapildy consume any saving made on such equipment.

Any description of inspection methods is again outside the scope of this paper, but the writer would remark that in our own case equipment is not deemed to have passed inspection when accurate to blue print requirements, but must produce work to the desired specification laid down on the component print.

The inspection of gauges in use in production is rather a knotty problem in an organisation like our own in which certain gauges, one might almost say all gauges, are in more or less continuous use.

A schedule of inspection has been laid down giving a stated period within which any particular gauge must be inspected. The schedule varies according to the nature of the gauge, the working tolerances, number of pieces produced per day, etc. A record is kept of all gauges and their points of usage, and the date and time of inspection is logged on a record card. Travelling inspectors are used wherever possible for the purpose of such checks.

Storage and Issue of Equipment.

On completion of inspection of new equipment same is passed to principal tool store, or in the case of standard tools to the tool bond. Receipt is registered on bin cards and stores location cards.

Sub-stores or tool cribs are located on each division and these tool cribs are the media of supply for operators within that division. A pre-determined float of tools required is issued to each crib as minimum stock, based on average usage, scheduled output of product, and time required for replacement deliveries being maintained in tool bond.

New tools are issued to operators on the receipt of expense material requisition signed by shop foreman. Tools once issued to production from cribs are charged off to the division as tools consumed and form the basis of a monthly report of tool usage. Used tools returned for grinding, etc., may continue to be drawn without charge until worn out. Expense material requisitions are returned to tool bond daily, and replacements issued to tool crib so that tool crib stock of unused tools is maintained at one consistent level. As soon as issues to cribs from tool bond reduces stock to the minimum re-ordering automatically takes place.

As an example of the close way in which tool usage is checked industrial diamonds are numbered, and when returned from divisions for re-setting the weight of diamond consumed is charged up to the division concerned. This close check upon divisional tool cost leads to close investigation of abnormal usage of any particular class of tool, and has led to a considerable reduction in overall tool cost per unit of production in the period within which it has been operated.

Machinery Maintenance.

All machine tools are numbered on arrival in the plant and a machine record card is filled in giving full description of machine.

This record card forms a history sheet of the machine, as all repairs are entered thereon together with date of repair, nature of fault found, reason for breakdown, and cost of repair.

A weekly return of machine tool repairs is made to production engineer, production manager, and factory manager.

Minor repairs are made on request from production areas by issue of machine breakdown card, and are charged to the appropriate division.

Complete overhauls of machinery can only be carried out by issue of internal work order issued on the authority of the production engineer, and sanction by management.

Lubrication of all machine tools is carried out systematically by men appointed for that purpose. Any excessive oil consumption by a given machine is reported and inquired into, and repair or re-adjustment is usually found necessary.

A continuous process of machine adjustment is also carried out; slides, saddles, turrets, etc., receiving attention and spindle bearings being adjusted or caps let down. This adjustment process has been found materially to decrease the number and cost of *major overhauls*.

Replacement of Production Machinery.

Replacement of machinery should be based on the following factors :—

(1) Obsolescence causing excessive maintenance or production cost.
(2) Inability to produce work to the standard of quality required in reasonable production time.
(3) The introduction of new types of machinery giving sufficiently increased productive capacity to justify purchase.
(4) Changes in manufacturing procedure causing demand for different class of machinery.

When requesting the replacement of machinery the following data should be supplied.

(*a*) Cost of new machine.
(*b*) Secondhand value of replaced machine.
(*c*) Saving made in productive cost per annum based on a given scheduled output.
(*d*) Comparison of quality of product of replaced and new machines.
(*e*) Comparison of maintenance cost.
(*f*) Estimated time within which machine will pay for itself after allowing for interest on investment.

Introduction of New Machinery and Equipment to Production.

The writer is a firm believer in the virtues of demonstration by persons competent to explain the use and principles of new machinery and equipment.

The primary demonstration of new machinery should always be

carried out by demonstrators sent by suppliers, and the purchase of such machinery should be deemed completed only when such demonstration has been carried out to the satisfaction of the customer.

Physical demonstration by a specialist of every piece of new equipment is, of course, impossible in such a rapidly changing sphere as the motor car industry. Nevertheless the try-out of new fixtures and tooling should be supervised by a competent demonstrator who should first explain to the operator the basic principles of operation.

The initial product of such tools and fixtures should be accurately inspected, and if error is found to exist, tool inspection department should be *called in immediately*.

Supervision of Equipment in Use by Production.

Continuous flow being the ideal behind production schemes, it has been found necessary to arrange for specialists to be at the call of production to solve any difficulty arising from defective or wrongly used equipment or machinery. These specialists should be controlled by the production engineer and should report to him direct so that immediate steps may be taken to get production flowing as quickly as possible. These men not only deal with troubles which arise, but watch for any inefficient equipment or methods and report on same, suggesting improvements or alterations. They also watch that the correct operational sequences are maintained as laid down, any deviation from operation sequence is inquired into and if advantageous, is reported upon and if thought advisable, embodied in the scheme. This does not prevent suggestions from production to production engineer, but if anything is found, to stimulate suggestions for improvements a special request for alteration form is supplied to production for that purpose. No suggestion is turned down without inquiry, and if not accepted, reasons are given in a courteous manner even though suggestions may be ridiculous. Many useful suggestions are put forward from the most unlikely quarters.

Personnel.

The writer holds strong views as to the training of personnel engaged in production engineering activities. Choosing between the purely technical or purely practical man, the writer would prefer the practical man. The ideal is a happy combination of the two and is really hard to find.

The trouble with the technical man is his lack of vision. He is inclined to work entirely to the text book and cannot analyse what will happen when practical application of his ideas is carried out. Generally speaking he is pretty sound in principle, but comes

unstuck in detail. On the other hand the purely practical man is what the writer terms dumb. He knows what is required, but cannot put it over to other people. With the gradual elimination of the old type of skilled mechanic, the demand for men of high calibre for the production engineering side will continue to increase.

The writer would suggest that the apprentice type is the hope of the future, and should be framed as follows :—

(1) A sound practical training combined with some technical training and draughtsmanship during his apprenticeship.

(2) An attractive salary on completion of apprenticeship calculated to stimulate his loyalty and interest in the firm.

(3) A period of not less than three to five years on demonstration and tool troubles, and studying operational processes.

After this training he is reasonably grounded in the requirement necessary for planning or jig and tool design. The right type will get more real knowledge from the last period in the shops than he would in ten years in the drawing office. He has the opportunity to see for himself the mistakes made by other people, and also their successes, and will, by the nature of his duties, be called upon to analyse the reason for such failures and successes. His faculties of induction and deduction will be sharpened and he will inevitably realise the basic fact that success in the production engineering field is only attained by strict and unswerving attention to detail.

When one looks back on the various troubles and failures, either of process or equipment, it is amazing to find how many are caused by this lack of attention to detail, and how few major mistakes get beyond the design stage.

No member of the staff of a production engineering division from the production engineer down to the office boy can afford to ignore detail. The profession is by no means an easy task master, but the principal reward to a man really interested in his job lies in the achievement of an evenly flowing high grade product.

Discussion, Luton Section.

MR. S. CARLTON-SMITH (Section President) : I have great pleasure on behalf of myself and all present in expressing our appreciation and thanks to Mr. Jenkins. It is particularly gratifying to us that we have one of the members of our own section who is an authority to give us this lecture on such an important subject, which is of interest to all members—not only to a certain number of them. It has been a most interesting paper and I am sure we have all enjoyed it.

MR. THORPE : It would greatly interest me to know, after seeing all the sheets and forms, which make one fully realise the amount of paper and clerical work to be done, just what percentage is left for the paying of the actual job—the percentage of the cost to the upkeep of all this—and what percentage is actually left to pay the operator.

MR. JENKINS : I cannot say anything definite about the percentage you require. At some works to-day, I think, 100 per cent. pays. At one time, the average number of cards issued for 2,000 production was 45 per week, now it is 90 per day.

MR. THORPE : I should like to know, for every pound paid out in wages, what is the cost in those works for all the time and stationery expended in planning and progressing the work ?

MR. JENKINS : I am afraid I cannot answer that question.

MR. S. CARLTON-SMITH : I take it that Mr. Jenkyns has this information but this is one of the times when it cannot be given.

MR. THORPE : Such a large amount of money must be spent to keep up all the paper work, which money could be saved to instal advantageous machinery ; thus production would be cheaper and cheaper.

MR. JENKINS : Get systematic methods. The clerical labour can be cheap and the cost of the paper is amazingly small. The increase of the clerical work, dealing with the production side, is comparatively small if done systematically. Every gain in results is achieved by it. For some time past this has, I think, been looked upon as beneficial. It lowers cost of production and (though not found in smaller establishments), it saves the time of the foreman and operator running about looking for information which should be at their finger ends.

MR. STAFFORD-FOX : With regard to the machine, which the speaker mentioned, using excessive oil. After full consideration about this machine, was it merely motor trouble or was there anything wrong with the oiling ?

MR. JENKINS : The makers, at first, were inclined to emphasise

the reason to be excessive oil pressure. They are now taking immediate steps to alter the design and apply the modifications to existing machines as several machines were out on the market at that time.

MR. SOUTHWELL: May I ask if the machines referred to by the lecturer were pressure-fed machines?

MR. JENKINS: Yes. As regards the question of using special or single-purpose machinery, think well before you decide that it is beneficial to use special purpose machines. Unless the machines are to operate any lengthy time on one part, use standard machinery. Ninety-nine per cent. of cases pay you to use standard machines, perhaps with special equipment, rather than to design a special machine. For special standard parts required in large numbers, have special machinery.

MR. GILBERT (Member of Council): There are one or two points which would be affected by different conditions existing in different departments or different factories. I think all standard conditions of output and calculations of times consist of necessary brainwork to be found entirely by the production engineer and his staff, but not always for conditions departing from standard. People have difficulties and the great point is in having proper planning, and pausing to consider the actual men, machinery, and equipment, to do the work from the psychological point of view. If you consider a series of schemes and decisions you get tempted to try out how you can make them on the shop floor. I would say that the production engineer really commences before the design of the production has reached a reasonable stage. I think it is very unfortunate if the production engineer is not called in at the earliest stage of construction and laying down new factories. I think the question of future extensions is not taken into consideration seriously enough. When laying down a factory on a site it would pay to pause and visualise what the future will probably require in the way of extensions. There is not enough foresight in regard to extensions and sites.

With reference to stampings and castings at various works, it would in many cases be an advantage if the production engineer had a voice in regard to the source of supply. Already the production engineer specifies tools for operations and specifies the source of supplies. An extremely important part is tool cost. If you buy a tap for 4d. it would probably tap say 50 jobs and a 4s. tap would tap 10,000. The production basis, I think, is a very important point.

MR. JENKINS: Speaking of the production engineer's responsibility in regard to production work, I would add that production programmes should give the whole of the production and tool production methods. But I do not believe in being hide-bound.

On more than one occasion a labourer has taught me something. To dream on a new site of an extension is, of course, getting back to the ideal. Where it is practicable the production factory should be laid down in sections with alternate buildings and spaces to provide room for another bay between each section and so in time be able to double the actual output. In the interim, however, you are faced with the loss of transport from bay to bay, but when the time comes for extension, provided that it is not too long delayed, you are more than compensated for that loss. As regards the supply of tools, the production engineer should certainly determine the sources of supply and grades of tools. I specify what I require and the supply department supply what I have asked for. If they purchase from other unsatisfactory sources purely with the intention of saving money, the production engineer and this department come to a disagreement.

MR. S. CARLTON-SMITH: Mr. Gilbert mentioned the voluminous number of forms provided under the highly organised system for instructions from the production department and for intercommunication, and said that it would be more to the point if a form was provided for reports from the production manager to the production engineer in regard to tools and equipment that were found in the shops not to give the performance expected of them. I have just been looking through the dossier of specimen forms passed round by the lecturer, and though the system may be criticised as being voluminous and perhaps not very handable unless thoroughly studied, and those concerned are thoroughly acquainted with it, there is somewhere amongst these forms for that particular purpose, I think, form No. 6005. There seems to me that there would come a point in the system that attempts to embrace everything where those responsible for carrying out the work on the shop floor would not have the time or be able to remember where the forms are accessible.

MR. J. RONALD: I think Mr. Jenkins' interesting paper shows us how system and organisation may save a vast amount of unnecessary and inefficient work. I must say that I am in agreement with his remarks as regards apprentices. I agree that they should be paid for what they actually do. I have nothing more to say or criticise only that I certainly do agree with the apprentice scheme.

MR. JENKINS: Thank you, Mr. Ronald.

MR. BROOK: I would suggest that great benefit may be derived by conferences being held between the managing director and the heads of all departments concerned when alterations come along.

MR. JENKINS: I entirely disagree with conferences. They do not get the thing right. The production engineer should, when alterations arise, find the most economical way of operating same and find out if it is necessary for new machines to be installed. With this

information he should then report to the managing director, explain the alterations, what exactly it will save, what is the cost of scrap and how much it will cost to put through this alteration.

MR. BROOK: At a works where I was once employed it was customary, every Friday morning, to hold a conference, regarding alterations, etc., between the managing director, production engineer, chief inspector and works.

MR. JENKINS: Conferences are damnation. I do not attend very many, for whilst one is attending a conference things are not going on correctly in the shops.

MR. SIDDALL (Member of Council): Referring to troubles arising, or any difficulties, in stampings and castings, Mr. Jenkins, you specify that these are to be supplied to approved samples. The samples may be correct and approved but what happens to your organisation of production in cases when bulk supplies fall short of samples? Also, what happens when machine breakdowns come along, or jig or fixture or any other necessary part of the equipment?

MR. JENKINS: As regards supplies, to be quite frank, we deal with defaulting supplies with the big "bludgeon." We deal with the supply department for not supplying what we called for. If possible we get the supplier along, and if he cannot put in an appearance we go along to him ourselves. We aim at keeping to one supplier, not necessarily the cheapest. If he submits a sample which proves satisfactory to us we get a supply from him. Castings must suit our jigs and fixtures. Keeping to one supplier we should get over our troubles. We make sure that the important parts will clean up and that the supplier can work to requirements of shape and size. Then we insist upon him taking back rejectable castings and making our castings right. In the mass production shop 40 per cent. is "line production" and 60 per cent. is the ordinary shop procedure. To overcome excessive overtime, motor, machine, and all breakdowns are dealt with immediately. Spare parts are carried in stock. You may hear that a works has sent a number of men home at 4-0 p.m. on a certain day. This, in some cases, is done to repair a breakdown and not because of lack of work. The following day people will work excessive hours to make up for the time lost on that breakdown.

MR. THOMAS: I should like to point out one statement as regards using a "sledge-hammer" on the supplier who delivers hard castings. The cost of the casting is slight compared with the cost of the trouble with the tools.

MR. JENKINS: We certainly do use "sledge-hammers" to check quickly such faulty work. If there is no response the supplier loses the job. It is not always the supplier who is at fault. Sometimes it is ourselves for ordering urgent supplies of castings with insufficient time to cover annealing processes, etc.

MR. MASON: Referring to the question of deliveries against

customers' demands, when deliveries are required earlier than shewn on the original delivery schedule given by sales, also rush orders, what methods have you in dealing with these deliveries ?

MR. JENKINS : Referring to rush orders for standard products we work to a given schedule, a production schedule, slightly ahead of the sales demand, which is based upon the sales schedule. In this way we get material in hand. We are just like everyone else, we cannot produce everything without the capacity. No actual individual arrangements are made to put material through the works—we have got production flow and it is just forced through the shops. Work through the factory is by definite deliveries and dates laid down really somewhere about three months ahead. This, of course, is likely to fluctuate up or down, on varying sales demand. The production schedule should be ahead of the sales requirements. You must of course, work to a schedule. A new schedule is required every fortnight. The production schedule is actually higher than the sales requrements. For sudden rush orders there are emergency methods.

MR. GILBERT : Breakdowns of all descriptions are serious things where line production is carried out and just as serious in a shop not laid out for mass production. Repairs should take place as soon as possible. (He gave a description of a breakdown which occurred at a motor works recently and remarked upon the superlative measures and supreme effort of everyone concerned to effect the repair at the earliest possible moment.) Flowing production showed the importance of this. You jump to it to get machines running again.

MR. JENKINS : Increase your investment of finished parts. This is a great advantage to production.

MR. HARPER : Talking about getting gear boxes through the shop in time, delivery is an important point. How many weeks does this represent before he gets any out ?

MR. JENKINS : Six weeks.

MR. PARKER remarked upon Mr. Jenkins' statement that the production engineer should state the source of supply of the material.

MR. JENKINS : He may suggest which supplier he prefers to supply the material. As a production engineer, I have nothing to do with the supply of the material. I think, you may be mixing up the supply of material with the supply of tools. The production engineer must control the supply of tools, but as regards material—No ! He must have some voice in the particular class of material supplied to the shop. The supply department are very concerned with the primary cost of the material itself. The supply department saves money in primary cost and the production side has to spend it, if the material is not right.

MR. PARKER : Must we understand, referring to source of supplies

that to get material from two suppliers instead of being solely dependent upon one source, this is not right ?

MR. JENKINS : Supply department should not alternate between two suppliers. You get the best supplies from one supplier. You can only get what you pay for.

MR. PARKER : Take supplies from any source. They have a specification sent, you wait for samples and the sample goes to the production engineer for his remarks. This is to prevent you getting into serious trouble. One other thing I should like to mention in the case of our suppliers, is that they send down a representative regularly with supplies. We have very little trouble.

MR. JENKINS : It is particularly advisable to submit samples to the production engineer. One thing I must say in spite of all the equipment provided, no one has yet found any equipment to effectively rally deliveries.

MR. J. RONALD : It is not a good thing to put all your eggs in one basket, as you may unfortunately do when one supplier is called upon to supply all the castings. If you have more than one source you have something to fall back upon when supplies are not right. But in this case, you will find variation in shape and size and it is necessary for you to make your jigs to accommodate these.

MR. JENKINS : That is alright, but jigs are not made of elastic.

MR. LARSSON : To avoid being let down by your suppliers, I take it you carry a certain stock. Generally speaking, how large would that stock be, expressed in number of working days or weeks ?

MR. JENKINS : We carry in stock somewhere in the region of 200 sets of parts. This actually represents about 2½ days' supply. That is to say, if the delivery is overdue we can carry on for 2½ days afterwards. Our supplies are delivered pretty regularly.

MR. BROOK : The material supply department is partly a clerical department, which works to a specification from the engineering side I am inclined to think that in some firms the outside purchases are left too much to a clerical staff. This staff should be provided with a specification passed by the engineer. This is the kind of thing which happens : A 10-in. dia. × ½-in. thick brass disc was required in the shop and the purchase department, being unable to obtain sheet material locally, supplied a ¼-in. thick casting, leaving it to the shop to cut down to the required thickness, a difficult and costly turning job.

MR. JENKINS : As regards the purchases departments, all material supplies are inspected and we insist on samples. These samples are reported upon, passed to the inspector for inspection and only ordered on receipt of the production engineer's instructions. We, like everyone these times, expect something approaching what we want. The purchase department is partly clerical but tied down by tight specifications.

MR. FENSOME : May I ask a few questions regarding the method of inspecting ? Should not the inspection of the finished product be as rigid as the inspection of the raw material coming into the works ?

MR. JENKINS : Yes. Every product should be inspected satisfactorily and every purchaser should receive a twelve months' guarantee.

MR. FENSOME : If a customer gets a twelve months' guarantee he expects it to last longer than that.

MR. JENKINS : Where the class of work permits I think that customers should be invited to come and see the inspection carried out for themselves.

MR. SWAIN : Where there is material flow through the shop, the work can be inspected during its flow without much trouble. Finally, inspection should be applied to the completed article. Women may be usefully employed upon inspection work, as they seem to be expert critics.

MR. BROOMHEAD : This paper is a very interesting one but, as I have said before, it would be better if we all had copies, as Mr. Jenkyns rattled away the first fifteen to twenty minutes. Nevertheless, I feel sure that it is a paper worth having read again. The first thing that struck me was the work. If people are brought together they can do anything if they are allowed to spend the money. Henry Ford has said that money is no object, it is the production you want. They spend money and get what they are aiming for. At one time Ford was producing 45 cars per week now they produce 90 per day. It is a great advantage to have co-operation between managing director, production engineer, draughtsman, and operator.

MR. JENKINS : If you spend money wisely you are saving it. You spend to save. The most efficient methods of production certainly pay. Set to work and instal these methods. If not satisfied with the methods, bring them up and up again until they are satisfactory. When a change takes place in the works the management should want to know what the change will cost, what it will save and the necessary tool and machine equipment that it required to carry out this change. As regards co-operation, I think there is no trouble at all in getting that. I am entitled to speak to my managing director as man to man, and I expect the labourer to speak to me in that manner.

MR. SIDDALL : I have pleasure in proposing a vote of thanks to Mr. Jenkins and I must say that this has been a very interesting paper indeed, and I feel sure that everyone has enjoyed both lecture and discussion.

MR. JENKINS briefly acknowledged the vote of thanks.

Addenda to the Discussion on Mr. J. D. Scaife's Paper on Machine Tool Development.

(*Editorial Note.—We have been requested by Mr. Scaife to publish the following corrections to the report of the discussion on his Paper that appeared in our September issue*).

Reply to Mr. Carlton Smith, p. 389.—In the paper I pointed out that not only was there no technical objection to the rotation of main spindles by hydraulic power, but advantages could be claimed. For instance, the increase of torque with speed reduction is a strong point in favour of the hydraulic method. Against this, however, is the considerably greater cost and loss of power due to the low efficiency of even the best type of hydraulic power unit.

Reply to Mr. Ronald, p. 389.—Replying to Mr. Ronald's concluding remarks, the kind of power can affect the result in this way. If a spring were fitted to the end of the broach you would get an effect somewhat similar to that observable in hydraulic broaching. Whilst the oil itself is unyielding the pipes, etc., are not and the tendency to jerky pulling is owing to this yielding under a varying load. My contention is that the application of hydraulic power to broaching machines has not been an improvement in principle, and I believe that further development of the screw operated machine would have done everything required at less cost.

Reply to Mr. Barnes, p. 390.—Hydraulic motors and pumps are considerably more expensive than electric motors, especially where variation of speed is required, but the advantages of the former method must not be overlooked. In the case of the electric motor either of the A.C. commutator type or D.C., a drop in speed represents a drop in power whereas in the case of the hydraulic variable speed motor there is no drop in power due to a drop in speed, and a higher torque or turning effort is available when it is required, that is when machining larger diameters. Generally speaking a superior quality of workmanship is required for hydraulic mechanism than for gearing which accounts to some extent for the extra cost. Regarding plunge cut grinding by hydraulic principles there are two methods in use that I know of. In one of these methods the wheel is pushed directly on to the work by a piston which is operated by a controlled amount of oil let into the cylinder. In another method which we employ, the wheel is brought into the grinding position by the method just described, and the feed to the wheel is then controlled by a screw which is hydraulically rotated. Backlash is prevented by another hydraulic piston. I believe a more positive

control of the feeding is achieved by the latter method. However both methods get away from the limited range available for gearing.

Reply to Mr. Broomhead, p. 390.—Regarding the relative life of broaches on the two types of broaching machines under discussion, personally I have no data on this point. I have observed such hydraulic machines in use, and my remarks are based on a general objection to the use of a piston and cylinder arrangement where a *direct push or pull is required to overcome a high and varying load at a constant rate.*

Reply to Mr. Weatherley, p. 392.—After " efficient," line 1, page 392, insert : " In the case of one of the best known systems mentioned in the paper and which I was interested in some years ago, actual demonstration on a motor lorry showed that only 70 per cent. of the speed obtainable with the regular gears could be obtained by the hydraulic system in spite of everything that could be done to improve the conditions."

Reply to Mr. Pudge, p. 392.—After " change gear box," line 4, add : " The cost of hydraulic motors as I have already stated, far outweighs any advantages they have for the larger units for main drives." Leave out the rest of my remarks to Mr. Pudge.

Reply to Mr. Pudge, p. 393.—After " for " in last line, add : " Lathes meet all requirements in practice."

Reply to Mr. Lee, p. 393.—Regarding cooling. Troubles from heating are not so acute as formerly. Improvements in oil circuits, valve gear design and more suitable oils have helped considerably.

Reply to Mr. Lee re air pistons, p. 393.—Air pistons would be impossible for the work we are talking about on account of the compressibility of gases.

Reply to Mr. Ripling, p. 393.—The trouble may be due either to the grade of oil used or to the design of valve gear. In shops where the temperature varies greatly an oil with a specially low temperature pour test is advisable.

Reply to Mr. Allen, p. 394.—I have a great respect for Mr. Allen's opinion on all matters concerning anti-friction bearings and perhaps it is only to be expected that under the circumstances we should have opposite views on such an important matter as main spindle bearings. However, I have no hesitation in affirming that the arrangement I have shown using bearings of the necessary accuracy is the best possible one using anti-friction bearings.

There has never to my knowledge been a failure or a replacement due to legitimate wear and tear, and Messrs. Alfred Herbert, Ltd., have used the arrangement continuously since it was first suggested to them some eight or nine years ago. Certainly the most accurate machinery and careful assembly is required, but main spindle bearings must have this anyway to be successful.

I am sure that Mr. Allen's firm would not put out anything that was not in every way satisfactory, but at the same time it is obvious that the double spherical roller bearing cannot have the same length of life, other things being equal owing to the much lesser surface area under load. There is, with the self aligning principle, a distinct advantage but the spindle will have to be larger in diameter to avoid a tendency to whip at high speeds.

Reply to Mr. Allen and Mr. Carlton Smith, p. 394.—The parallel roller bearing in this particular application is made to a specially high grade of accuracy unattainable in any other type of bearing except a ball bearing, otherwise the tight fitting bearing which is equivalent to a preloaded bearing would not be possible.

Reply to Mr. Lee, p. 395 (*second question*).—The air will usually work out of any hydraulic system if further air is prevented from entering. If the circuit is bad and air locks are formed then constant trouble can be expected. All joints on the suction side should be definitely air tight and exhaust oil deposited below the oil level of the tank and not splashed in. Are you referring to recent trouble ?